Using Multispectral Imagery to Target Priority Areas for Field Surveys of Indicators of Ecological Sustainability for Tropical Forests

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~7% of Earth Surface
47% of Forest Cover
50% of World Species
Carbon Stocks
Environmental Services
Forest areas that are not considered productive have been / are / will be transformed into other land uses, such as pasture and annual crops.

Sustainable management as an alternative......

But how to implement it?
Criteria & Indicator Processes

• Based on theory and basic scientific research
However....

- Most Ecological C&I indicators and verifiers are surveyed in the field
- Logistical constraints
  - Time
  - Extent
  - Expensive
  - Personnel

Limitations increase as area under management increases
• The need for an approach to prioritization of survey areas becomes evident.

A possible solution…
Forest management can change forest structural heterogeneity (Pinar and Putz 1996).
• **Indicator 1.2.1.2.**

“The change in diversity of habitats as a result of human interventions are maintained within critical limits as defined by natural variation and/or regional conservation objectives”

• Also usually measured in the field

It can be measured using *remote sensing & spatial statistics*
Dung Beetles

• Associated with faeces of mammal and vertebrate fauna in general.
• Decomposers
• Key link in nutrient cycling
• Secondary seed dispersal
• Easy to sample
• Stable taxonomy
• Various levels of sensitivity to disturbances
• If you catch them it means they are actually using the habitat
• Proven useful

(MSc Thesis 1999)
Objectives

• To establish whether remotely-sensed imagery can be used to identify priority areas for field surveys of dung beetle species diversity and composition.

• To determine relationships between observable heterogeneities in forest canopy reflectance, forest management practices, and dung beetle community structure and composition.
• Hypothesis 1

More [less] intensely managed or disturbed forest areas will [not] exhibit differences in canopy reflectance heterogeneity dynamics as observed by spaceborne sensors as compared with natural control areas.
• **Hypothesis 2**

Managed forest areas that [do not] exhibit differences in canopy reflectance heterogeneity dynamics as compared with natural areas will also [not] show differences in dung beetle species diversity and community composition.
Wide Dynamic Range Vegetation Index
(Gitelson 2004)

\[
WDRVI = \frac{\alpha \rho_{NIR} - \rho_{RED}}{\alpha \rho_{NIR} + \rho_{RED}}
\]

\[0 < \alpha < 1\]
\( \alpha \) as a nonlinear contrast tuning knob
3D structural heterogeneity of a rainforest area as seen with WDRVI data derived from a Landsat TM satellite image.

We can see forest structural heterogeneity.
Sill, range, and nugget variance values allow quantifying forest structural heterogeneity.

The values are estimated by fitting a nonlinear spherical model to the semivariogram derived from WDRVI data.
Natural Area

Natural

Average Dynamic Change

Natural + Management

Managed Forest Before selective logging

Managed Forest After selective logging
Average dynamic change Shown by natural forests represented by changes in Sill, Range, and Nugget Variance parameter coefficients.

Reference for managed areas: “Natural Variation Limits”
Study Area and Data

- Costa Rica
- 2 Landsat 5 TM images
  - 1986 (before logging)
  - 2001 (after logging)
- 28.5 x 28.5 m pixel size
- Roughly the size of a forest heterogeneity field survey area unit.
- Natural Areas (6) vs. Managed (15)
  - \( \leq 5 \) trees cut per hectare
- WDRVI semivariography
- Changes (%)
  - Sill / total variation
  - Range
\[ \alpha_{est} = 2 \times \frac{\text{average } \rho_{\text{red}}}{\text{maximum } \rho_{\text{NIR}}} \]

Henebry et al. (2004)
Results

% change in sill / total variation

% change in range

Natural
Managed
Logging intensity (trees/ha)

% Change in total variation
• Hypothesis 1

More intensely managed or disturbed forest areas exhibit differences in canopy reflectance heterogeneity dynamics as observed by spaceborne sensors as compared with natural control areas.
Dung Beetles Survey

Braulio Carrillo National Park

La Selva

Costa Rica
<table>
<thead>
<tr>
<th>Forest</th>
<th>Individuals</th>
<th>Species richness</th>
<th>Diversity estimates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Observed</td>
<td>Estimated total</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>+/- 2SE (Chao mean)</td>
</tr>
<tr>
<td>Natural</td>
<td>335</td>
<td>11</td>
<td>11.73 a</td>
</tr>
<tr>
<td>Low</td>
<td>262</td>
<td>11</td>
<td>11.32 a</td>
</tr>
<tr>
<td>Moderate-Low</td>
<td>269</td>
<td>14</td>
<td>14.97 b</td>
</tr>
<tr>
<td>Moderate</td>
<td>197</td>
<td>12</td>
<td>16.83 b</td>
</tr>
<tr>
<td>High</td>
<td>265</td>
<td>7</td>
<td>7 c</td>
</tr>
</tbody>
</table>
Hypothesis 2

Managed forest areas that exhibit differences in canopy reflectance heterogeneity dynamics as compared with natural areas also show differences in dung beetle species diversity and community composition.
Biological survey data

Species

Dissimilarity matrix

Species

FMU location

WDRVI values

Logging intensity

Digital Elevation Model

WDRVI range

Forest structure heterogeneity

Euclidean distance matrices

Ferrier et al. (2002)

\[
- \ln(1 - BCD_{ij}) = a + b_1 (x_{1i} - x_{1j}) + b_2 (x_{2i} - x_{2j}) + \ldots
\]
<table>
<thead>
<tr>
<th>Surrogate Variable</th>
<th>Kendall Matrix Correlation Coefficient with Bray Curtis Dissimilarity Index</th>
</tr>
</thead>
<tbody>
<tr>
<td>Geographic distance</td>
<td>0.116</td>
</tr>
<tr>
<td>WDRVI $\sigma^2$ (2001)</td>
<td>0.163</td>
</tr>
<tr>
<td><strong>WDRVI total $\gamma(h)$ 2001</strong></td>
<td>0.471*</td>
</tr>
<tr>
<td><strong>WDRVI Range 2001</strong></td>
<td>0.535**</td>
</tr>
<tr>
<td>$\gamma(h)$ Change between 1986 and 2001</td>
<td>-0.116</td>
</tr>
<tr>
<td>Range Change between 1986 and 2001</td>
<td>-0.023</td>
</tr>
<tr>
<td>Mean elevation</td>
<td>0.209</td>
</tr>
<tr>
<td>Elevation variance</td>
<td>0.023</td>
</tr>
<tr>
<td><strong>Mean slope</strong></td>
<td>0.209</td>
</tr>
<tr>
<td>Slope Variance</td>
<td>-0.023</td>
</tr>
<tr>
<td>Mean aspect (slope orientation)</td>
<td>-0.070</td>
</tr>
<tr>
<td>Logging intensity index (m3/ha)</td>
<td>0.023</td>
</tr>
<tr>
<td><strong>Logging intensity index (in trees /ha)</strong></td>
<td>0.349*</td>
</tr>
<tr>
<td><strong>Priority for survey (linear)</strong></td>
<td>0.675**</td>
</tr>
<tr>
<td><strong>Priority for survey (binary)</strong></td>
<td>0.547*</td>
</tr>
</tbody>
</table>
Compositional dissimilarities = \( f \) \{ Priority for survey (linear) + Logging Intensity (trees/ha) + Mean Slope \}

Model selection made using the Akaike index and derived analysis.

RMSE = 0.078 (=8%)
Conclusions

• Variography applied to the WDRVI enabled characterization of the structural heterogeneity of dense tropical forests and its change through time.

• A prioritization system based on remote sensing showed significant agreement with dung beetle community structure and composition, a well-known ecoindicator.
Conclusions

• Established links between dung beetle community structure and composition, forest structural heterogeneity and its dynamic change, and one of the main forest management variables: logging intensity.

• Central hypothesis was supported: managed forest areas that did [not] exhibit significant differences in forest structural heterogeneity as compared with natural areas also did [not] show significant differences (as losses) in dung beetle community species diversity and composition.
Recommendations

- Additional areas need to be surveyed. Our sample size is small.
- **Additional indicators** in the areas surveyed in the present work (plants, birds, butterflies, etc…)
- **Similar evaluations** need to be made in additional areas.
  - Other FUNDECOR FMU
  - Additional areas from different forest management operations (Bolivia and Brazil)
- **Additional vegetation indices** (other than WDRVI) should be tested.
Recommendations

• Other sensors.
  – Ancient Landsat 5 TM
  – Dysfunctional Landsat 7 ETM+
  – Other alternatives such as EO-1 ALI, SPOT, ASTER and even MODIS for large forested areas.

• Logging intensity threshold need to be considered carefully
  – Pilot study with small sample size
Remote sensing of forest structure dynamics cannot replace field work.

“Scientists can continue to gather data when models or experiments fail, but managers and policy-makers must choose a course of action.Delaying action in the hope that new information will resolve the problem has become the “regulator’s dilemma” [Weinberg 1985] (...) as with delay can come the risk of rapid environmental deterioration and irreversible damage (Sklar & Hunsaker 2002)”
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Questions?